Investigation of the Effects of Water Ageing on the Fracture Toughness of Novel Composite Materials

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Project Aims

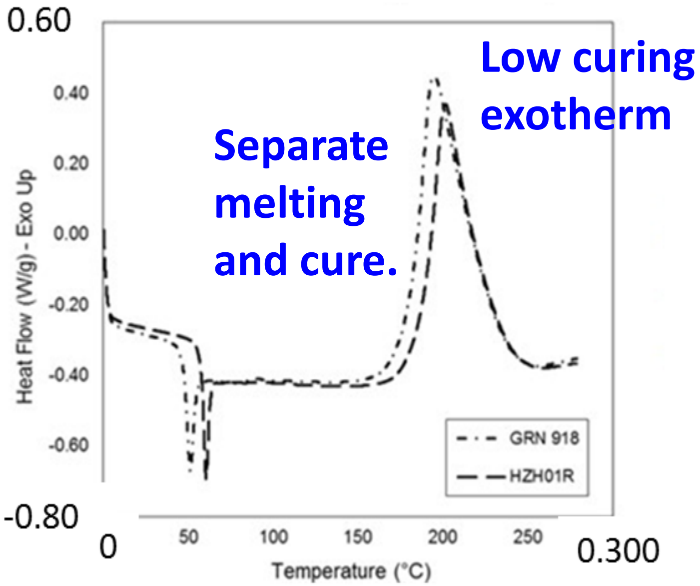
- Manufacture **high quality powder epoxy** carbon and glass coupons
- Understand the **water absorption characteristics** of these materials
- Determine the **mode I and Mixed Mode Fracture** toughness of **dry and saturated** samples
- Investigate the effect of **hygrothermal aging on fracture mechanics**
- Use results as the **input for delamination modelling** in composites with high risk of delamination such as tidal turbine blades

Presentation Overview

- I. Introduction
- II. Specimen Preparation
- III. Test Setup
- IV. Results and Findings
- V. Future Work
- VI. Conclusions

I. Introduction: Powder Epoxy

- **Heat activated cure**: Separate melting and cure
- **Can be stored at room temperature**
- **Low viscosity (down to 1 Pa.s)**
- **Low exothermic reaction**, allowing for faster production of thick composites
- Suitable for **out-of-autoclave manufacturing**
- No VOCs and no material waste
- Tailored for **large composite structures** such as turbine blades



Low curing exotherm

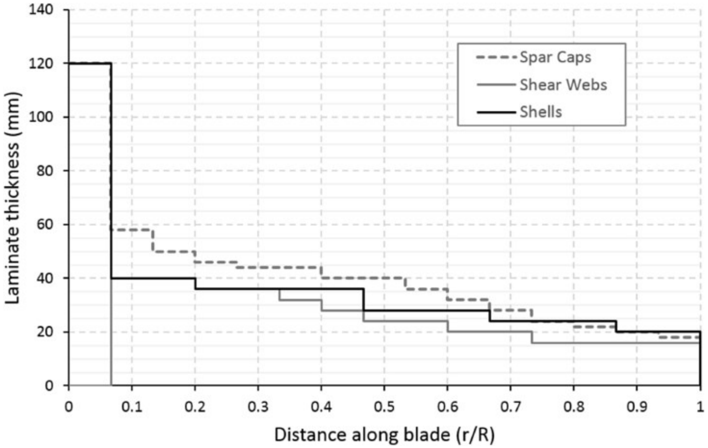
Separate melting and cure.

Differential Scanning Calorimetry

Maguire, J.M., Nayak, K, and Ó Brádaigh, C.M., (2018) “Characterisation of Epoxy Powders for Processing Thick-Section Composite Structures”, Materials and Design, Vol. 139, pp. 112-121

I. Why are we interested in Toughness?

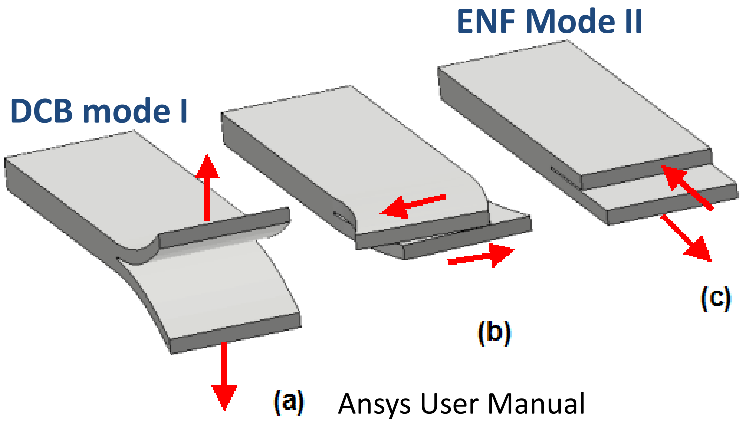
- Work is carried out as part of a study on delamination of tidal turbine blades
- Rapid transition from a circular root to hydrofoil
- Thickness reduction from root to tip by dropping plies
- **Risk of delamination** in tidal blades is **enhanced** which may become saturated in water
- **Delamination rate is governed by toughness**



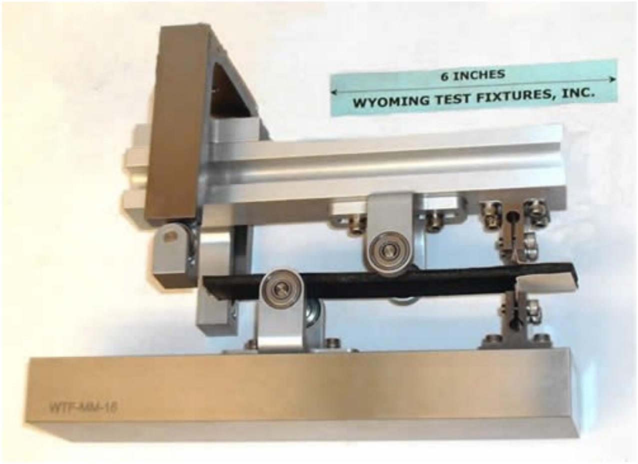
Fagan, E. M., Kennedy, C. R., Leen, S. B., & Goggins, J. (2016). Damage mechanics based design methodology for tidal current turbine composite blades. *Renewable Energy*, *97*, 358–372.

I. Introduction on Composite Toughness

- 3 modes of fracture: Normal and two Shear Directions
- Mode I test: Double Cantilever Beam (DCB)
- Mode II test: End Notch Flexure (ENF)
- In real applications cracks propagate in a mix of the shear and normal modes
- Therefore, Mixed Mode Bending (MMB) test can be carried out to obtain the properties in more realistic fracture cases



Ansys User Manual



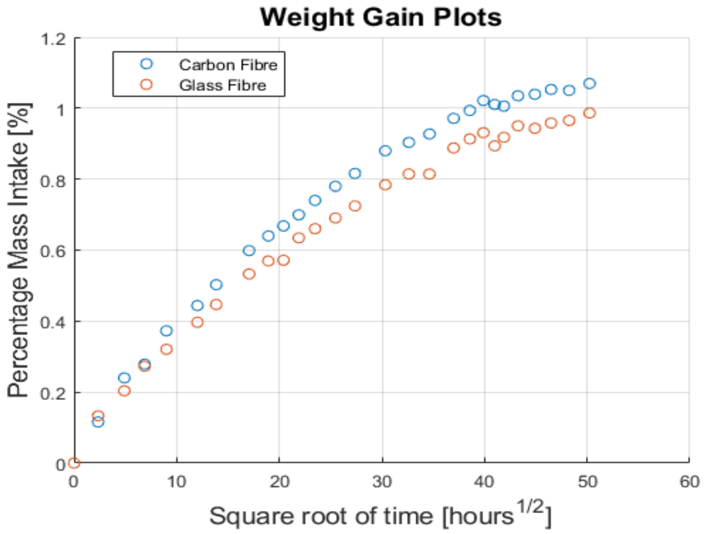
Wyoming Test Fixtures: **MMB Mixed Mode**

II. Specimen Preparation

- Plates manufactured using UD glass (with 10% 90° fibres) and carbon (with 3% ±60° fibres) fabrics around 600 GSM from Saertex
- Powder epoxy used as resin
- Fibre Volume Fraction of 50%±2%
- Optical microscope observations demonstrate that no macro voids are present.
- 180mm X 24mm X 3.5mm coupons extracted from plates with 13µm thick Teflon insert
- 72 coupons (36 carbon and 36 glass) for MMB test
- 24 coupons for DCB (mode I) test

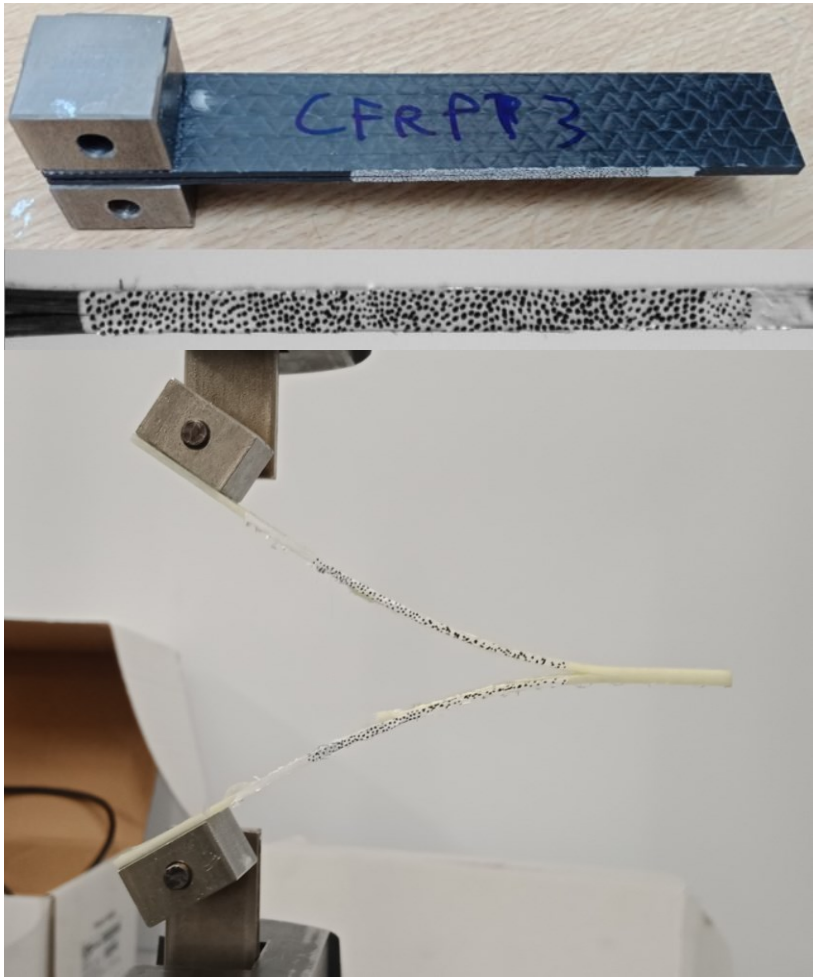
II. Saturated Samples

- Specimens were immersed in 60° C seawater for 4 months
- Mass intake stabilised after 3 months
- Saturation of water around 1.05% for the carbon and 0.98% for the glass composites
- Stainless steel loading blocks bonded with samples partially immersed to avoid desorption prior to testing



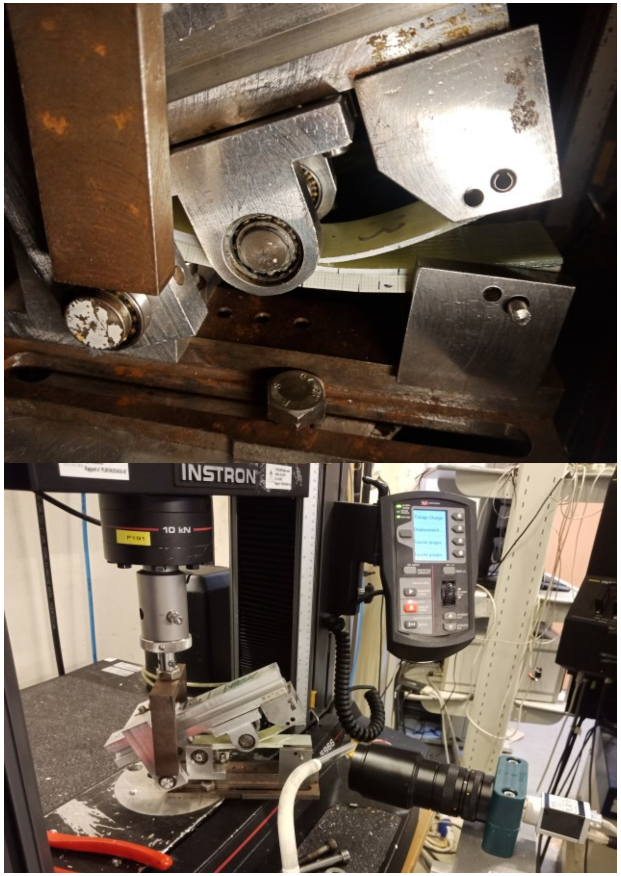
III. Test Setup: DCB

- Test performed according to ASTM D 5528
- Displacement rate of 2mm/min at loading point
- DCB samples tested on 3369 Series Instron Universal Test Machine
- Imetrum video extensometer used to track crack growth



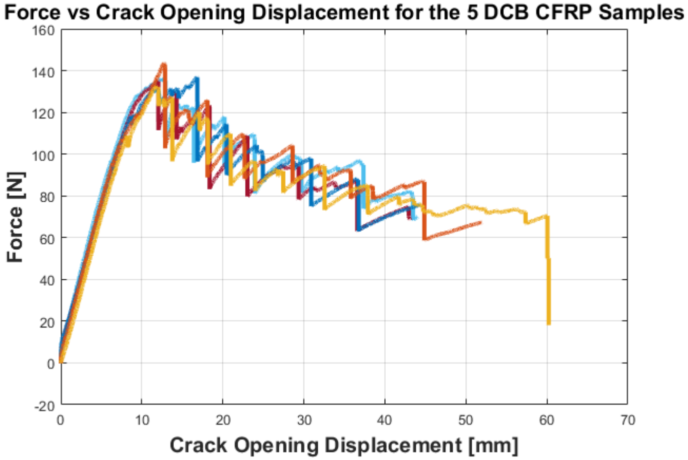
III. Test Setup: MMB

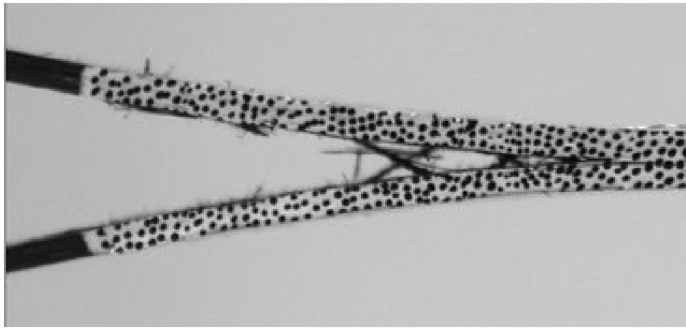
- Test performed according to ASTM D6671
- Displacement rate of 2mm/min at loading point
- Mode ratios of **25%, 50% and 75% mode II** were tested with 5 specimens at each ratio
- Load and displacement measured using Instron Test Machine
- Crack extension measured using a camera and graph paper glued on the bottom of specimens



IV. Results: DCB Test

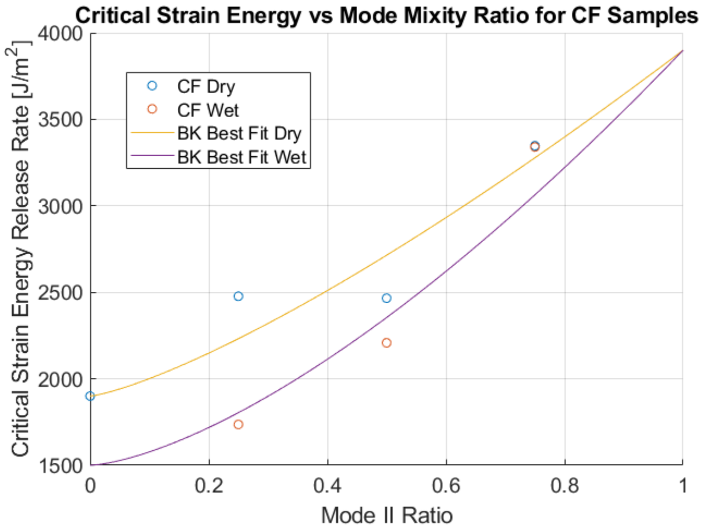
- CFRP samples displayed **stick slip** behavior due to presence of off-axis fibres
- GFRP had smoother force-displacement curve
- The mode I toughness was measured as **1900±57 J/m^2 for CFRP** and **2217±351 J/m^2 for GFRP**
- **Significantly higher toughness** than found in literature for epoxy composites -> Lower risk of delamination
- Very good consistency between CFRP samples (COV of 3%) but high variability in GFRP Samples (COV 15.8%)

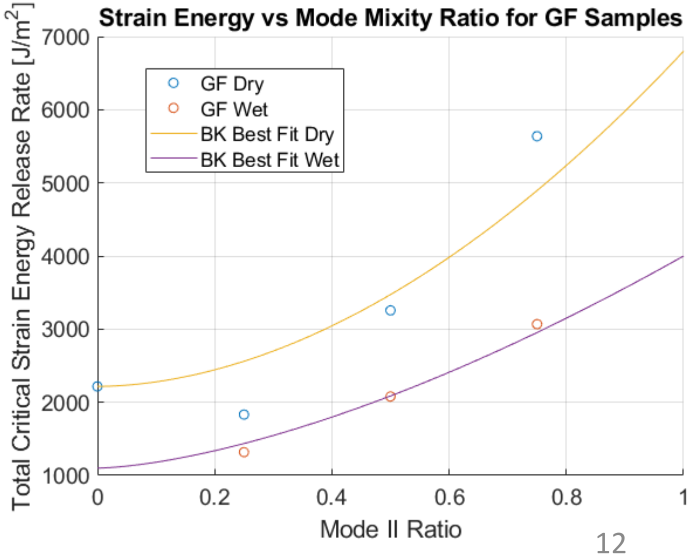




IV. MMB Results

- Saturated **CFRP 30% drop in 25% mode II**, a 10% drop for 50% but **no significant reduction for the 75%**
- Saturated GFRP had a similar drop in **25% mode II** but an even higher drop as mode II was increased with a **45% reduction in 75% mode II** toughness.
- The toughness for 25% mode II GF was lover than for the DCB -> This will be investigated.
- Curve fitting: Benzeggagh-Kenane criterion (BK)
- Influence of fibre configuration, interface properties or fibre stiffness?





IV. Summary of Results

			DCB	25% Mode II	50% Mode II	75% Mode II
Carbon Fibre	Dry	$G_c\ (J/m^2)$	1900	2477	2466	3347
		Standard Deviation	57	146	212	540
		COV (%)	3.00	5.89	8.60	16.13
	Wet	$G_c\ (J/m^2)$		1736	2208	3340
		Standard Deviation		223	171	203
		COV (%)		12.85	7.74	6.08
		Difference (%)		29.92	10.46	0.21
Glass Fibre	Dry	$G_c\ (J/m^2)$	2217	1832	3256	5638
		Standard Deviation	351	168	383	506
		COV (%)	15.83	9.17	11.76	8.97
	Wet	$G_c\ (J/m^2)$		1318	2079	3068
		Standard Deviation		146	320	398
		COV (%)		11.08	15.39	12.97
		Difference (%)		28.06	36.15	45.58

V. Future Work: Explain Observed Differences

- ILSS to be conducted on wet/dry specimens
- Thorough Analysis of SEM pictures captured from fracture surfaces
- Refine the MMB Curves by performing DCB tests on wet coupons and ENF (100% mode II) tests

VI. Conclusions

- The water absorption kinetics at 60C was obtained and mass uptake was found to be in the low range for epoxy composites
- The **mixed mode fracture behavior** was characterized for glass and carbon composites
- The observed behavior were **different** for glass and carbon composites and was likely **influenced by the off-axis fibres**
- More tests need to be carried out to understand the observed behavior, especially at the microscale.

Thank you for your attention!

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POWDERBLADE